ENGINEERING GEOLOGIC REPORT
FOR
ANDERSON RESERVOIR SPILLWAY
FALLS AREA

Prepared for:
Santa Clara Valley Water District
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1.0 INTRODUCTION

1.1 PROJECT DESCRIPTION

Water spilling from Anderson Reservoir flows first through a concrete spillway that ends in a dentated flip bucket fairly high on the right abutment of the Dam. From here the water flows through a channel excavated in Franciscan Complex bedrock and alluvial/colluvial deposits to a steep rock face created as a borrow pit for Dam construction. After falling some 80 feet, water impacts the gently sloping rock floor of the old quarry where it continues westward, eventually rejoining Coyote Creek.

A small but continuous flow originates as ground water in the vicinity of the concrete spillway lip, drains across the rock spillway channel, and continues down the rock face in the central falls area. On those occasions when Anderson Reservoir spills, the rock face turns into a spectacular waterfall visible for miles. The spill of 1997 caused considerable erosion in portions of the rock spillway banks, the southern edge of the falls area, and the area east of the quarry floor.

1.2 PURPOSE AND SCOPE

This report presents the results of a reconnaissance-level geologic investigation of the Anderson spillway falls area. The purpose of the investigation was to establish the existing general surficial geologic conditions at the site, identify potential geologic hazards, to work with the Santa Clara Valley Water District (District) to develop possible mitigation measures if required, and suggest additional exploration if necessary. To do this, the following tasks were accomplished:

- Background geologic and aerial photo review;
- Field mapping on March 28 and 29 by Phil Frame and Jim Nelson;
- Compilation and analyses of geologic data
- Report preparation, meetings, and discussions.

1.3 PREVIOUS INVESTIGATIONS

The vicinity of the spillway falls area has been mapped at a regional scale by numerous geologists including Rogers and Williams (1974) and Dibblee (1973). Pacific Geotechnical Engineering (1991) show the geology of the area at a scale of 1 inch = 200 feet as mapped for the town of Morgan Hill. Wahler Associates (1987) mapped the walls of the spillway cut to the crest of the falls area at a scale of 1 inch = 20 feet as part of their work on the spillway enlargement.

2.0 LOCAL GEOLOGIC SETTING

The Anderson Spillway falls area is located at the northeastern margin of Santa Clara Valley where Coyote Creek flows from the Diablo Range onto the valley floor. The hills here are mostly underlain by Jurassic- and Cretaceous-age rocks of the Franciscan Complex which continue below the valley floor but are now capped by alluvium. Older alluvial deposits also can be found as isolated remnants on the lower hillslopes.

Aside from being composed of more resistant materials, the mountains bordering the valley floor have also been uplifted by fault movement. The Coyote Creek (thrust) fault often forms the contact between Santa Clara Formation on the southwest and serpentinite on the northeast. Locally this lies at the valley floor/hillfront boundary but more often lies within the lower hillslope. It is mapped as passing beneath the concrete spillway at Anderson Dam (Dibblee, 1973; Rogers and William's, 1974; Pacific Geotechnical Engineering, 1991; Coyle and Anderson, 1992). Dibble (1973), Pacific Geotechnical Engineering (1991), and Coyle and Anderson (1992) map a second, concealed fault at the base of the hillslope at the Dam. These faults show Quaternary activity (Jennings, 1994) and lie within City of San Jose (1983) Special Studies or Potential Hazard zones. The Holocene-active Calaveras fault crosses the hills 1.4 miles northeast of the site (CDMG, 1982a; 1982b).

3.0 SITE CONDITIONS

3.1 GEOMORPHOLOGY AND RECENT HISTORY

Aerial photographs taken in 1939 show the site prior to any development. The hillslope here rises abruptly from a concave-north-arcing meander of Coyote Creek. A step or abandoned river channel follows along contour part way up the hillslope in the vicinity of the present spillway. Two old landslides can be seen directly above (north of) this bench as shown by Nilsen (1972). Two ravines were eroded in the area straight down the hillslope to Coyote Creek. Grass and trees covered the slope except for a few brushy patches.

By the time of the 1979 photos, the hillslope had been extensively modified for construction of Anderson Dam which took place in 1955. The spillway appears to be cut along the general alignment of the bench identified in the 1939 photos while the brushy knob at the west end has been removed presumably for rock borrow in dam construction. Most of the slope below the spillway has been modified with cuts and fills but regrown with trees and brush except for the road extending from the crest of the dam.

The existing rock portion of the Anderson Dam spillway is about 50 to 60 feet wide across the base and oriented N65E. It slopes westward very gently until it daylights at the quarry face which is oriented N65W. This creates the spillway falls where water drops about 82 feet over the irregular rock surface as shown on Cross Section A-A¢. The overall slope of the rock face is 53°. Water has eroded a plunge pool directly below the spillway while the remainder of the quarry floor is bare rock covered locally with sand to boulder-sized clasts that remain from quarrying or have fallen or washed onto the surface. The quarry is open on the west and has a low wall about 20 feet high to the south. A northeast-trending rock ridge 20 to 40 feet high and 100 feet long presently extends from the southeastern-most quarry face but does not appear on photos as recent as 1987. I presume this ridge was produced by erosion during the 1997 spill event.

3.2 GEOLOGY

3.2.1 Geologic Units

The distribution of surficial geologic units at the Anderson Spillway falls area is shown on the accompanying geologic map; a cross section showing anticipated subsurface conditions along the axis of the spillway (A-A¢) is also shown. Units encountered at the site are described below in order of decreasing age.

Franciscan Complex Rocks
All bedrock exposed on the spillway falls area is part of the Franciscan Complex. We have divided these into several units:

- Greenstone (KJfgs) - fine grained; rare pillow structure; greenish-gray to yellowish-gray; intensely fractured to massive, generally sealed and tight but some fractures are open, little staining; hard; strong to very strong; little weathering to fresh.
- Chert (KJfch) - thinly bedded, 1/2 to 2 inches thick with shale partings; dark reddish-brown to medium gray; intensely to closely fractured especially along bedding; very hard; strong; little weathering to fresh.
- Mixed greenstone (≈ 2/3) and chert (≈ 1/3) (KJfgc) - tectonically mixed; intensely fractured, foliated locally; hard; moderately to very strong; little weathering to fresh.
- Shale (KJfsh) - medium dark gray; intensely fractured, stained with iron oxide; hard; weak, moderate weathering; exposed only on the north spillway wall upstream of the falls.
- Sandstone (KJfss) - light olive gray; fine- to medium-grained; angular to subrounded; closely to moderately fractured; hard; strong; little weathered exposed only on the east side of the shear zone beyond the area of map coverage.

Shear Zone (sz)
Tectonically mixed but recemented rocks were mapped on either side of the spillway. These rocks are little fractured, moderately hard to hard, moderately strong, and moderately weathered. A dark gray clayey gouge believed to be part of the same shear zone is exposed at the southwest end of the 1997 erosional channel. This material is of low hardness and weak, but fresh. The age of the shear zone is unknown but probably is similar to the age of the adjoining Franciscan Complex rocks.

Older Alluvium (Qoa)
Older, inactive alluvium is well exposed at the head of the ravine recently eroded southeast of the falls. This material is composed of weakly consolidated tan, gravelly sand characterized by subrounded clasts. Signs of other alluvial deposits are found north of the spillway where rounded clasts are mixed with colluvium. These could be related to an older alluvial terrace as suggested on aerial photographs or be part of the Santa Clara Formation as mapped by Wahler (1987). A thin layer of colluvium (Qc) partly covers the older alluvium exposed north of the spillway.

Recent Alluvium (Qal)
Active alluvial deposits blanket the floor of the ravine east of the quarry. Elsewhere, alluvial boulders are scattered locally in the spillway and quarry floor but are not shown on Figure 1 due to their limited extent.

Artificial Fill
Two types of artificial fill have been identified in the spillway falls area. Large blocks of riprap (rr) measuring several feet in size were placed in areas of considerable erosion from the spill of 1987. These blocks line portions of both sides of the spillway and have also been placed at the end of the erosional ravine to divert flows back into the quarry. Gravel fill (gr) covers the access roads on the south side of the quarry and spillway. Locally the gravel fill caps riprap.

Recent Landslide Debris (Qls)
A debris flow landslide has developed near the head of the 1997 erosional ravine. This is an active landslide that developed recently and has moved within the last couple of years.

3.2.2 Water

At the time of our geologic reconnaissance on March 29 and 30, 2001 water was flowing down the central portion of the falls area as a low, but apparently perennial flow. This water can be traced upstream along the bedrock spillway channel to seeps at the end of the concrete spillway.

A spring having nearly as much flow as the spillway falls was identified to the southeast originating at the riprap/bedrock contact in the vicinity of the rock spires (see Geologic Map). This flow probably originates in the spillway and drains through the riprap to create the spring.

One seep was found in fractured greenstone on the southeast side of the lower quarry face.

3.2.3 Discontinuities

The Franciscan Complex originated as oceanic materials accumulation in a subduction zone. Tectonic forces churned the various slabs of basalt (now altered to greenstone), chert, sandstone and shale, then mixed these with more exotic rock types from deep within the earth's crust. More recent forces have uplifted, shaken, and offset these rocks further. The geologic history of these rocks has created many surfaces that result in planes of weakness unless they are cemented. The following discontinuities were identified in the spillway falls area:

- Bedding - The chert unit is well bedded and shows broad folding of the strata. Bedding orientation ranged from N80W to N40E, dipping northward at 10° to 55°. This is generally oblique to the quarry face.
- Foliation - The unit comprised of mixed chert and greenstone locally shows a planar foliation created by tectonic shearing during the time of it's formation. Most of these surfaces have been lithified and so are not considerably weaker than the adjacent rock.
- Fracturing - All of the bedrock in the falls area is fractured to some degree with spacing ranging from 1/4 inch to several feet. The fractures are generally tight, not stained, and randomly oriented. The only fractures shown on the Geologic Map are those that are open or represent a local prominent set.
- Faulting - Several faults have been identified in our mapping based on termination of rock units or the presence of slickensides or polished surfaces. The majority of slickensides indicate strike-slip or oblique-slip movement. The faults are presumed to be tectonically inactive but several are open and represent block landslide failure surfaces.
- Shear zone - The shear zone separating the greenstone/chert rocks (Marin Headlands terrane ?) from sandstone has variable physical properties. In some areas such as the erosional gully it is composed of black clayey gouge while on either side of the spillway channel the shear zone is a melange of recemented blocks locally more resistant than nearby fractured bedrock.

4.0 EVALUATION OF GEOLOGIC HAZARDS

The spillway falls are far enough removed from Anderson Dam so that even the worst possible failure scenario here would not impact the integrity of the dam. Two concerns should be considered though: (1) the potential of the existing steep quarry face to fail in either spilling or dry conditions; and (2) erosion by spillway water causing a breach in the southwestern wall of the old quarry that would allow uncontrolled water to flow through the park lands.

4.1 QUARRY SLOPE INSTABILITY

An unknown but not great amount of rock has fallen from the face of the old quarry since its use was abandoned. This is evident from the talus at the base of the cut to the northwest of the falls and the blocks at the base of the falls. Comparisons of older aerial photographs to the present configuration of the bluff face show relatively little change over the past 22 years. However, geologic mapping of the quarry face revealed several discontinuities open as much as 6 inches indicating movement of discrete rock wedges.

Rock faces such as the one excavated in the spillway falls area rarely exist under natural conditions. Without erosive forces such as water flowing through the spillway and given enough time (perhaps eons) the face would slowly crumble, eroding back at the top and building out at the base until a slope equivalent to the nearby hillslopes is achieved. If the spillway was to function for eons, the existing face would decrease in slope, achieve a more sinuous profile, and migrate upstream similar to a knick-point created by faulting.

For this report I have considered two failure scenarios: one is an annual or short term hazard that has the potential of occurring at any time; the other is the long term hazard which is based on a 50 year life of the structure and would include triggering events such as spills of Anderson Reservoir and large earthquakes. The type of failure in either case is expected to be rock falls, topples, or block glides rather than rotational or flowing-type of landslide.

Short Term

No rock falls occurred during the approximate 12 hour span that we were on site mapping, however, I would expect gravel size clasts to fall from the face nearly daily and boulder size clasts to fall occasionally during a year. From an engineering standpoint these do not decrease the stability of the slope although they could be precursors to larger falls. They could, however, pose a hazard to anything in their path.

The short term rockfalls probably result from blocks that have, over the course of several years had a decreasing factor of safety due to weathering, vibrations, frost wedging, thermal expansion, etc. Eventually the factor of safety falls below one and the block falls. The triggering mechanism could be as slight as a gust of wind, scurrying rodents, or unfelt seismic vibrations.

Long Term

Several open gaps have been identified along discontinuities in the rock at several locations on the rock face. These openings are the presumed result of imperceptible creep of the rock and mark one failure surface of a rock wedge. In some cases, such as at the crest of the falls, the gap runs parallel to the rock face and the limits of the loose wedge can be estimated with a fair degree of certainty. These gaps are at the head or back of the toppling block. At other locations, the gap is located at the toe of a creeping block and dips out of the face at low angles. Without knowing the extent or geometry of the failure surface beyond a few feet into the face, the size of the moving wedge cannot be determined. No open discontinuities were mapped on the rock spillway surface upstream of the falls.

The various causes contributing to short term slope instability contribute to long term instability as well. Two additional factors should be considered as well when assessing long term stability: spills of Anderson Reservoir and high accelerations from large seismic events. Water flowing over the falls (other than the perennial flow) will tend to wash fillings from cracks, pluck slabs from the top, add driving forces at the point of impact, and create vibrations in the rock. Vibrations are also created by seismic events. The probability of high seismic accelerations is increased in longer intervals of time. The probability of a magnitude 6.7 event on the nearby Calaveras fault before 2030 is 18% (WGCEP, 1999).

I could easily envision long term slope failures in the falls area of several yards in volume. Larger size slope failures are also possible but the size of these cannot be predicted without additional data on probable failure surfaces. If the quarry cut was designed today, a typical recommendation might be 0.5:1 (horizontal:vertical) or 63°. The overall slope at the center of the face is presently about 53° suggesting a failure of the entire slope is unlikely but that steeper portions of the face are probably unstable.

4.2 WATER EROSION

Erosion by water under normal circumstances is negligible aside from its impact on slope stability as discussed above. However, during the spill of 1997 flow was great enough to break through the southern spillway cut near the falls and erode a new channel to the old quarry floor. This channel came close to eroding through a low berm which would have resulted in water and sediment flowing through the County Park below. The path followed by this water seems to have developed in the Quaternary-age, poorly consolidated alluvial or colluvial sediments interpreted from aerial photographs and exposed in the southern wall of the ravine produced by the 1997 spill.

Following (or during?) the 1997 spill event large riprap blocks were placed in the breach of the southern spillway cut, along the base of part of the northern spillway cut, and at the lower part of the channel to maintain flow into the quarry floor (see Geologic Map). The two more southerly fills were capped with gravel to provide a smooth surface for walking or vehicles.

Water continued to flow in the ravine at the time of our investigation. The source of most of this water is a spring from beneath the riprap at the southern spillway cut. Seeps were also identified near the base of the Older Alluvium in this area and probably contributed to the formation of the debris flow landslide here. This water probably originates as surface flow in the bedrock spillway channel, flows along the base of the riprap and/or permeable alluvial or colluvial deposits, then daylights near the head of the ravine.

Presumably the existing riprap will protect slopes from erosion by spilling water in the areas where it has been placed. The old quarry floor and perimeter, where cut into bedrock, is also expected to suffer minimal erosion from water. Erosion of the Older Alluvium and clayey shear zone material bordering the ravine on the south side of the falls will continue especially if overflow spilling water drains through this channel.

5.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The present Anderson spillway falls originated as a quarry in hard greenstone and chert bedrock which was used in construction of the dam in 1955. The rock has several types of planar intersecting discontinuities that create wedge-type blocks susceptible to failure as rock falls, topples, or glides. A moderate amount of these blocks have fallen in the past and geologic mapping has revealed several open gaps that are likely to fail within the lifetime of the facility. The size and extent of these blocks is presently unknown. Volumes of several cubic yards can certainly be envisioned but a massive failure involving the entire face seems unlikely.

The worst consequence of a rock fall or topple would be personal injury. This could occur in failures of individual gravel size clasts as well as larger failures under some circumstances. If personal injury is avoided, slope failures below or north of the spillway lip would have limited impact on the safe operation of the spillway; rock would accumulate at the toe, some eventually washing into Coyote Creek, and the crest would migrate upslope or upstream. A slope failure below the southern portion of the falls area could potentially impact the spillway cut slope or riprap fill, allowing overflow water to drain through the channel carved during the 1997 spill. Continued flow in this channel would generate erosion and landslides in the weakly consolidated deposits on the southern and eastern bank, eventually causing a breach that could flow through the County Park.

5.1 POTENTIAL MITIGATION SCHEMES

The falls portion of the Anderson spillway have functioned as designed until 1997 when high flows created a new drainage path that nearly extended through the County Park. That pathway has since been blocked by riprap but has not yet been tested by high spillway flows.

Without knowing the District's level of concern in the spillway falls area, I offer the following suggestions of things that could be done to lessen potential geologic hazards. They are listed in general order of complexity. Some would require additional studies to investigate their feasibility:

- Post signs or fence off rockfall impact area. This would alleviate the main problem of personal injury.
- Cut a ditch through the center of the spillway channel to drain the water presently ponding there and potentially seeping through the riprap and Quaternary deposits. This should slow the steady flow of water from the spring beneath the riprap and in the 1997 drainage channel.
- Widen the spillway channel above the falls by cutting farther back into the north wall. This would decrease the chances of overtopping the spillway on the south by lowering the water level for a given volume of flow.
- Deepen the spillway channel near the falls with a cut that would extend upstream above the point where 1997 waters overflowed the channel. This also would lower spillway water levels as above.
- Install rock blots in the area beneath the southern side of the falls. This would mitigate against a slide that could remove the southern spillway riprap and reopen this channel.
- Seal ground-water flow through the southern spillway riprap by grouting or redesign of the berm.
- Remove rock spires which, during an overflow event, would direct water into the 1997 erosional channel.
- Backfill the 1997 erosional channel and slope the fill surface to drain toward the quarry, removing any part of the resistant ridge protruding above this surface. By doing this, overflow waters would be directed towards the existing quarry outlet and away from the County Park.

5.2 ADDITIONAL INVESTIGATIONS

I would recommend some additional work be done in the Anderson spillway falls area even if the District elects to do no repair work at this time. The purpose of this work is to provide a better baseline of geologic data that could be used to tell if conditions are worsening over time:

1) Ground check the site topographic map in the area of the spires where vegetation appears to have masked the true morphology; then check the geologic mapping against the new contours.

2) Annually photograph the quarry face and key open discontinuities so comparisons can be made.

3) Establish measurement points on either side of key open gaps to see if they are moving or the rate is increasing.

4) Do an annual reconnaissance of the spillway surface behind the falls to check for open gaps.

If the District decides to mitigate or further assess the rockfall or water erosion hazards, subsurface exploration would be necessary along with more detailed mapping:

5) Core drilling with a skid rig, perhaps with water pressure testing and/or video logging could be used to see how far into the face open discontinuities extend. If repairs are not planned for the near future, the holes could be instrumented to find depth of movement or a movement warning system developed. Borings should be located behind areas of concern, particularly in the vicinity of the 1997 breakout. Those located near the face should extend the full depth of the cut: farther back, the holes should extend down to a plane drawn at 1:1 from the base of the falls plus 10 feet.

6) The stability of the riprap placed in 1997 on the south side of the spillway channel is unknown to me. If as-built information is lacking, additional exploration is suggested to identify the type and erosion potential of material the riprap is placed on. Seismic refraction might be used to locate the base of riprap and indicate the seismic velocity of underlying materials (there should be a high contrast between older alluvium and bedrock). Drilling through the riprap material would be difficult but could be necessary to see if rock discontinuities extend beneath this part of the spillway.

7) If the 1997 erosional channel is left open and not backfilled, additional mapping, perhaps accompanied by hand dug test pits should be done to establish the extent of Older Alluvium and clayey shear zone materials. Shallow drilling on the existing dirt road separating this channel from the County Park could also be warranted to find the distribution of these materials here.

6.0 LIMITATIONS

The recommendations and opinions stated in this report reflect my current understanding of the project requirements. This understanding is based on the investigation and evaluation methods described in this report, and on the assumptions implicit in those methods. The site conditions and their impact on the design of the facilities may differ from the interpretations presented in this report. This may be due either to the inherent limitations of the investigation and evaluation methods, or to undisclosed or unforeseen variations in geologic and soils conditions.

My services on this project consist solely of professional consultation to aid in the evaluation of geologic conditions at the Anderson Reservoir Spillway falls area. The only warranty or guarantee made in connection with services performed for this project is that they were performed with the care and skill ordinarily exercised by members of the geologic profession practicing under similar conditions and localities at the time. No other warranty, expressed or implied, is made or intended by rendition of these consulting services, or by furnishing this written report of the findings.

The contents of this report are valid as of May 2001. Changes in the condition of the site can, however, occur with the passage of time as a result of either natural processes or human activity in the area. In addition, changes in the state-of-the-art of engineering geology may affect the validity of this report. Consequently, this report should not be relied upon after a period of three years without my review for verification of validity.

7.0 REFERENCES

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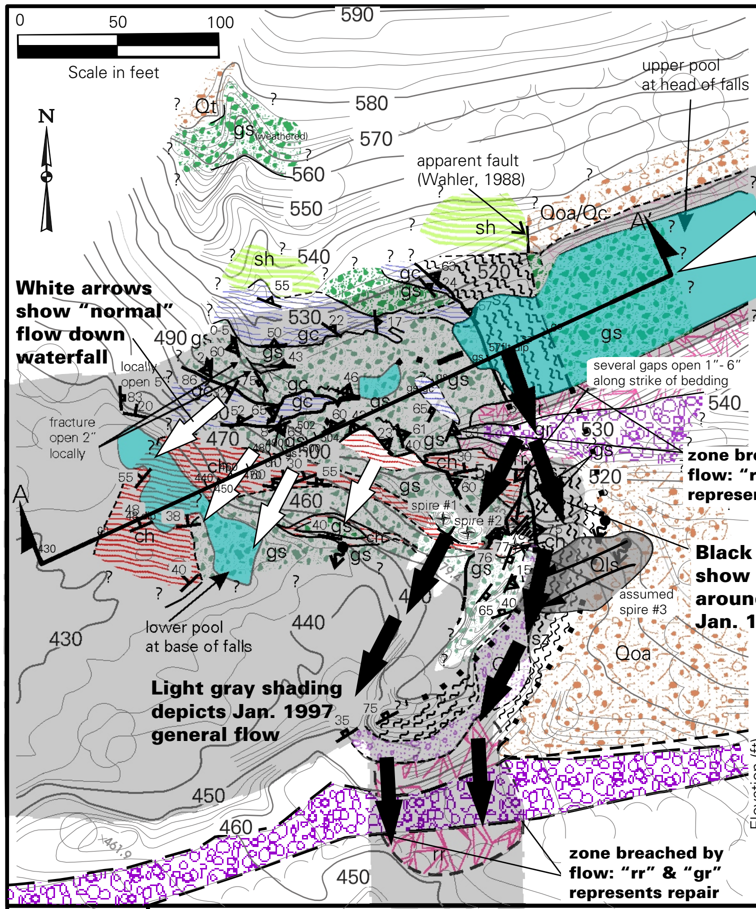


White arrows show "normal" flow down waterfall

zone breached by flow: "rr" & "gr" represents repair

Black arrows show flow breach around 3 spires Jan. 1997

Light gray shading depicts Jan. 1997 general flow

zone breached by flow: "rr" & "gr" represents repair

Explanation

Map Units

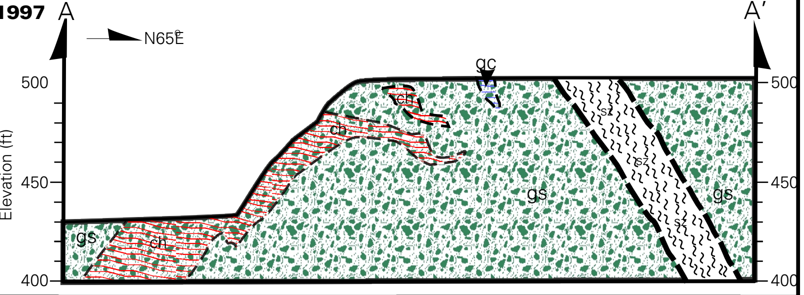
▨	gr	Artificial fill, gravel
▨	rr	Artificial fill, riprap
▨	Qal	Recent alluvium
■	Qls	Recent landslide
▨	Qc	Colluvium
▨	Qoa	Older alluvium

Franciscan Complex (KJf)

▨	ch	Chert
▨	gs	Greenstone
▨	gc	Mixed greenstone & chert
🟩	sh	Shale
▨	sz	Shear zone, possibly Franciscan

Map Symbols

- Geologic contact; dashed where approximately located; dotted beneath younger materials; queried where uncertain
- Fault contact; dashed where approximately located; dotted beneath younger materials; queried where uncertain
- Landslide: arrows show direction of movement
- 40 Strike and dip of bedding
- 78 18 Strike and dip of fault; small arrow shows plunge of slickensides
- 65 Strike and dip of foliation or shear fabric
- 70 Strike and dip of prominant fracture
- Shear zone
- Spring or seep
- spire #3 Bedrock spire
- Waterfall
- A A′ Location of geologic cross section



DATE	5/16/01
DESIGN	JLN
DRAWN	JLN
CHECKED	PF & RLV

Notes:
1) Mapped on March 29 and 30, 2001 by Phil Frame & James Nelson
2) File: W:\Geology\Nelson\DSOD\Anderson\Figures\CDR\spillterm.cdr

Santa Clara Valley Water District

Sketch Geologic Map and Geologic Cross Section of Anderson Dam Spillway Falls Area

Anderson Dam

SCALE 1″= 50′

FIGURE 1